Mapping Spatial Patterns of Gypsy Moth Defoliation Events in Glocester, RI Using Landsat Satellite Imagery

Jonathan Vitrano | Salem State University | Department of Geography | Geo-Information Science
Professor Marcos Luna
GPH 904 Spring 2018

Introduction

The health of our forests is not only imperative to the preservation of our landscape, but also to the economic and ecological health of our region as a whole. Defoliation occurs when pathogens or predators attack a plant's photosynthetically active leaves or needles. Hardwoods such as oak and maple are particularly susceptible due to energy storage methods employed by the trees and may die from just one defoliation event during peak energy production season (Rhode Island Department of Environmental Management n.d.). The accurate forecasting of future defoliation events has been a challenge over the course of the last century due to the rapid increase and expansion of forest defoliators because of climate change. However, predictions have become a much easier task with the aid of remote sensing technologies, such as multispectral satellite imagery from Landsat and MODIS (Rullan-Silva et al. 2013).

Detection and monitoring of damage occurring to forest stands has historically been analyzed through aerial sketch mapping, which collects and interprets damage over the course of multiple time periods, usually before and after damage occurs. While this method can be quick, depending on the area of interest, it tends to be costly and reveals inaccuracies due to the skill-level and sensitivity of the observer. Alternatively, satellite imagery can be utilized to cover larger areas at a lower cost much more quickly and and is similarly implemented across pre and post-defoliation periods in order to process a change analysis of tree crown traits related to damage or stress (Hall, Skakun, and Arsenault 2006; Rullan-Silva et al. 2013).

Using remotely sensed imagery to detect defoliation damage in vegetation has varied widely over its historical use. Classical approaches have utilized freely available Landsat data and used NDVI and NDMI indices to determine the relative "health" of a classified forested area. Other approaches have coupled aerial surveys with ground surveys and more recent studies have integrated "near-real-time monitoring" and Tasseled Cap Greenness into their methods (Hall, Skakun, and Arsenault 2006; Pasquarella, Bradley, and Woodcock 2017). Of particular interest are spatial studies such as that of Paritsis et al. (2011), where overlays of related variables such as topography, annual precipitation, and vegetation cover are used to establish models for indicating spatial correlation to defoliators. This type of overlay analysis, when applied alongside hot-spot spot models as seen in Qiang et al. (2017), would prove to be beneficial in identifying areas prone to defoliation in the future.

One primary defoliator, the gypsy moth, was introduced to the United States in 1869 from France. The gypsy moth was originally intended to be used as a silkworm crossbreed but quickly escaped captivity and became an invasive species feeding off the late spring/early summer foliage of hardwood trees across the eastern United States (Hall, Skakun, and Arsenault 2006). Southern New England, especially Rhode Island, has been hit hard by the gypsy moth with 226,800 acres of damage in 2016. This amount of widespread damage has not been seen since 1985 in Rhode Island and is likely attributed to low rainfall during early spring leading to reduced prevalence of pathogens which infect gypsy moth caterpillars (Rhode Island Department of Environmental Management n.d.).

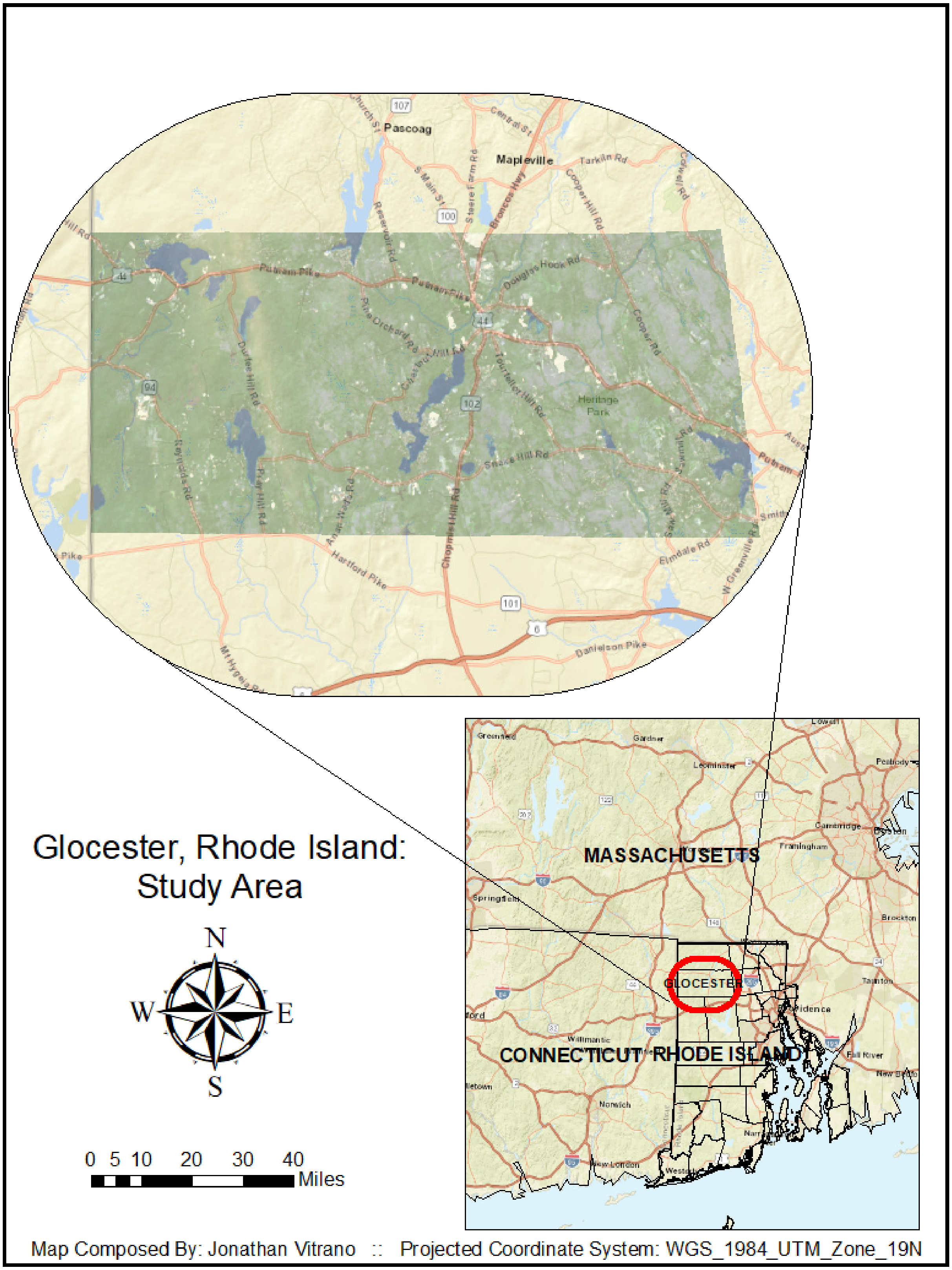
Objectives

The objective of this analysis is three-fold. The first objective is to produce defoliation event maps of before and during the spring/early summer defoliation event of 2016 in the heavily affected northwestern region of Rhode Island. Through the use of land cover classification and NDVI differencing, defoliation maps will be produced to determine defoliated and non-defoliated forest areas. This identification of heavily, lightly, and non-defoliated areas will then be spatially aggregated in order to determine clustering using a Local Moran's I analysis. This process will then be repeated for a similar event in 1985 to determine if spatial patterns can be predicted between events. Finally, these cluster analyses will be compared to forest land cover types to determine if there are any relationships between defoliation events and tree type.

Methodology

Study Area

The study area chosen for this analysis was based upon the Rhode Island Department of Environmental Management's report (n.d.) stating a marked increase in defoliation from gypsy moth caterpillar in the western part of the state. The town of Glocester, RI was chosen due to personal experience with the area's geography and high concentrations of hardwood forests, the primary food of choice for gypsy moth caterpillars, indicating a prime location for defoliation events. The surrounding areas of Connecticut and Massachusetts also experienced significant defoliation, but in a much less concentrated area making Glocester, RI a great choice for a spatial study.


Glocester, Rhode Island:
Study Area
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Miles
Map Composed By: Jonathan Vitrano :: Projected Coordinate System: WGS_1984_UTM_Zone_19N
Pascoag
Mapleville
Putnam Pike
Douglas Hook Rd
Heritage Park
Snake Hill Rd
Chopmist Hill Rd
Hartford Pike
Danielson Pike
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
GLOCESTER

Data

The data needed for this analysis included four remotely sensed Landsat images collected from USGS's Earth Explorer website, filtered by date, and less than 20% land cloud cover. Image dates can be seen in Table 1 below:

Landsat Satellite	Image Date
Landsat 5	June 22, 1985
Landsat 5	June 14, 1988
Landsat 8	August 6, 2013
Landsat 8	June 27, 2016

Table 1

Limited cloud cover over the area of interest was of utmost importance as it would interfere with the change detection used for the defoliation analysis (Pasquarella, Bradley, and Woodcock 2017). Many images had to be discarded due to excessive cloud cover in the area of interest. The dates above were chosen based upon availability of usable images and proximity to one another for time of year/season and the window of defoliation. The images of interest are June 27, 2016 for the recent gypsy moth defoliation event and June 22, 1985 for a similar defoliation event in the past. The two other dates served as a "control" group, with little to no gypsy moth defoliation occurring, which were used for an NDVI difference to highlight changes in canopy cover, indicating defoliation. Other data used in this analysis included two national land cover data sets from the Multi-Resolution Land Characteristics Consortium for 1992 and 2011 as well as political and town boundary shapefiles from RIGIS.org.

Data Processing

Note: All images imported into ArcMap 10.6 were clipped to the town boundary of Glocester, RI using a shapefile created from the 1997 Municipal boundaries shapefile obtained from RIGIS.

Data processing began with importing all four downloaded images into ERDAS Imagine2016 with a layer stack of the spectral bands of interest (bands 2-4 for Landsat 5 and bands 3-5 for Landsat 8). The two national land cover datasets from 1992 and 2011 were re-projected into the WSG_1984 coordinate system and class types 41 (deciduous forest), 42 (evergreen forest), and 43 (mixed forest) were selected out as a separate layer. Four Normalized Difference Vegetation Indexes (NDVI) were calculated using red and near-infrared spectral bands (bands 3 "red" and 4 "near-infrared" for Landsat 5 and bands 4 "red" and 5 "near-infrared" for Landsat 8 respectively) using the following formula is ArcMap's Raster Calculator tool: $\frac{NiR-Red}{NiR+Red}$ (Figure 1). These four NDVI images were then used to create two NDVI difference rasters using the Minus tool which subtracted all raster values between the two corresponding images of interest (1988-1985 and 2016-2013).

In order to distinguish between vegetated areas and non-vegetated areas in the NDVI difference analysis, a supervised classification was needed so that non-vegetated areas could be removed from the image before an image difference could be processed. The 1985 and 2016 images were classified using the Spatial Analysis Classification Toolbar. Fifteen training sites were created and merged into two classes: Vegetation and Non-Vegetation which were classified using the Maximum Likelihood classifier (Figure 2). The resulting classifications of the images were then transformed into a shapefile feature class using the Raster to Polygon conversion tool, preserving the two class-types as multipart polygons. A new classification polygon layer was then created from the selection of just the vegetated class and the new layer was used to clip the NDVI difference rasters so that non-vegetated areas were excluded. (Figure 3).

The resulting NDVI difference rasters were then classified into 3 quantiles to indicate high NDVI change (heavy defoliation), low NDVI change (low defoliation), and little to no NDVI change (no defoliation) (Figure 4). Both rasters were transformed to point features using the Raster to Point conversion tool and extracted as three separate point layers (high defoliation, low defoliation, and no defoliation) based upon the classified NDVI difference ranges. Each point layer was then spatially joined to a 180m fishnet grid in order to aggregate a count of each type of defoliation event within the new polygon layer (Figure 4). A Local Moran's I cluster analysis was then used to determine clustering of each aggregated point field for each of the three defoliation classes in both years (Figures 5-10).

Results

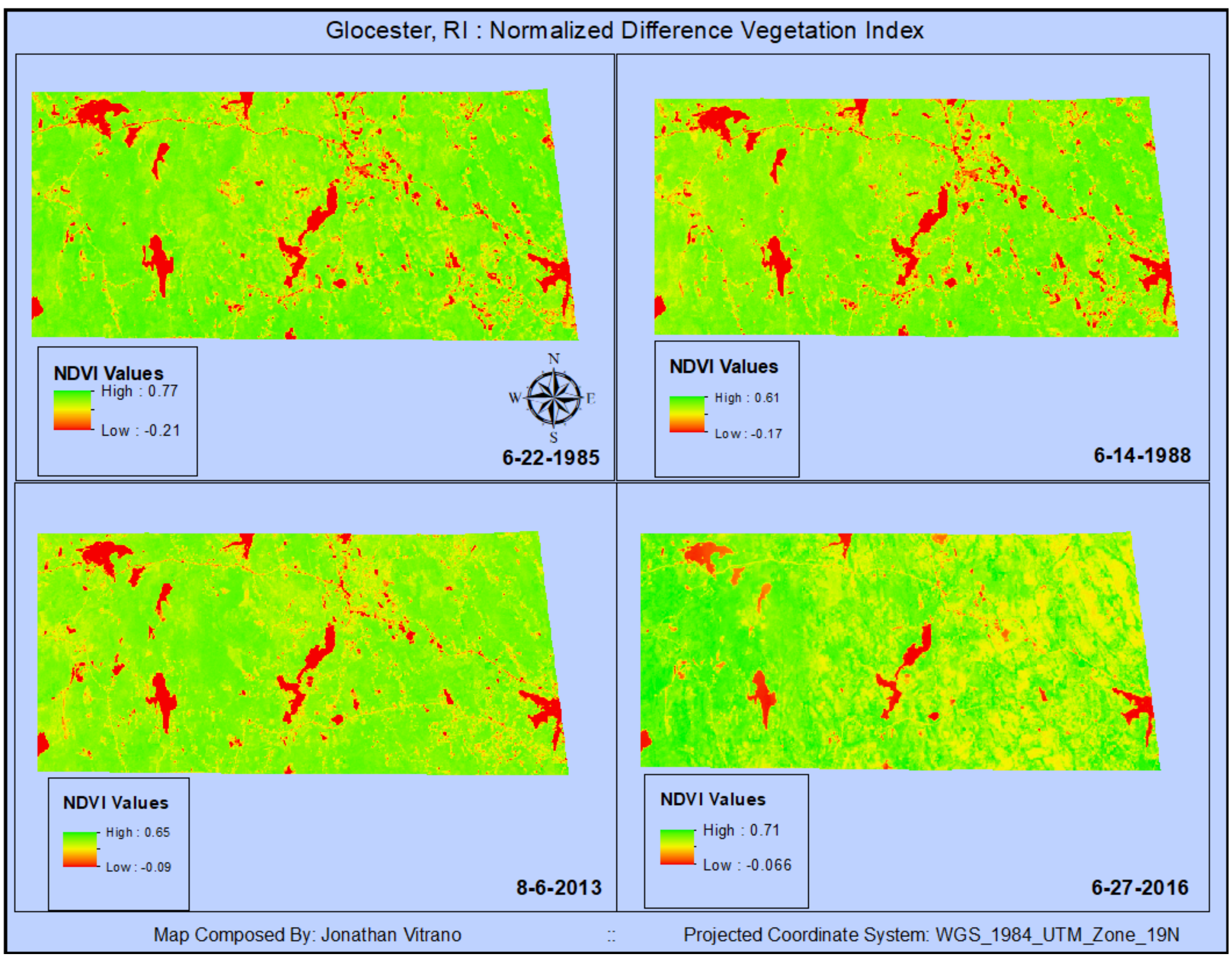

Figure 1

Figure 1 shows the NDVI calculation in raster format using NIR and Red spectral bands. The top two images are from Landsat 5 and the bottom two images are from Landsat 8. Both images are 30 meter spatial resolution and include both vegetated (high values) and non-vegetated areas (low values). Vegetated areas that are "stressed" or damaged will also show low values. These images alone cannot determine where damage has occurred without an NDVI difference of vegetated areas only, however some damage can be seen in the 2016 image, with the high concentrations of yellow versus the 2013 image. Damage is not readily apparent between the 1985 and 1988 images.

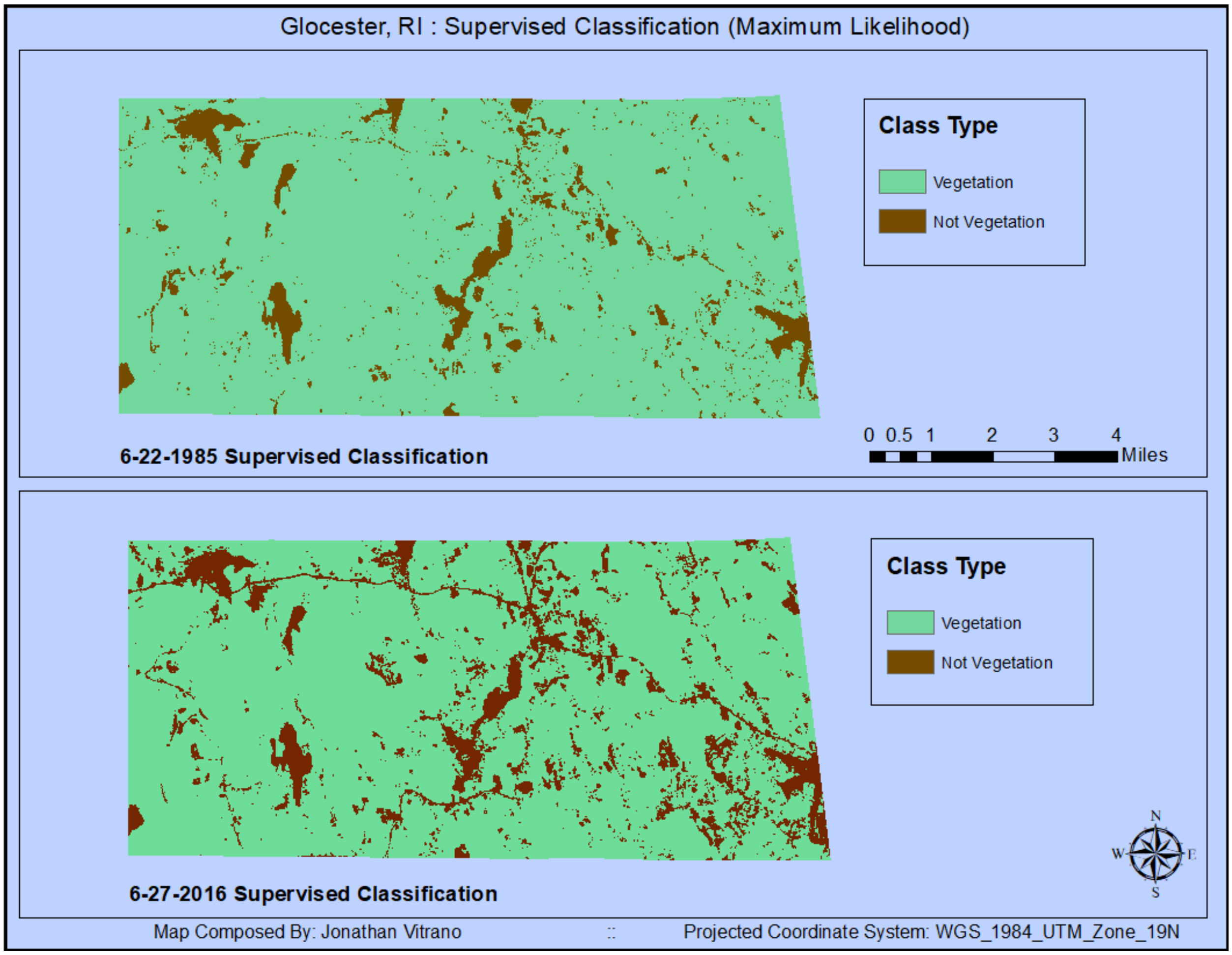

Figure 2

Figure 2 shows the two class supervised, maximum likelihood classification of the 1985 and 2016 images. This classification is used to clip out the portion of vegetated areas only in the NDVI difference images shown in Figure 3.

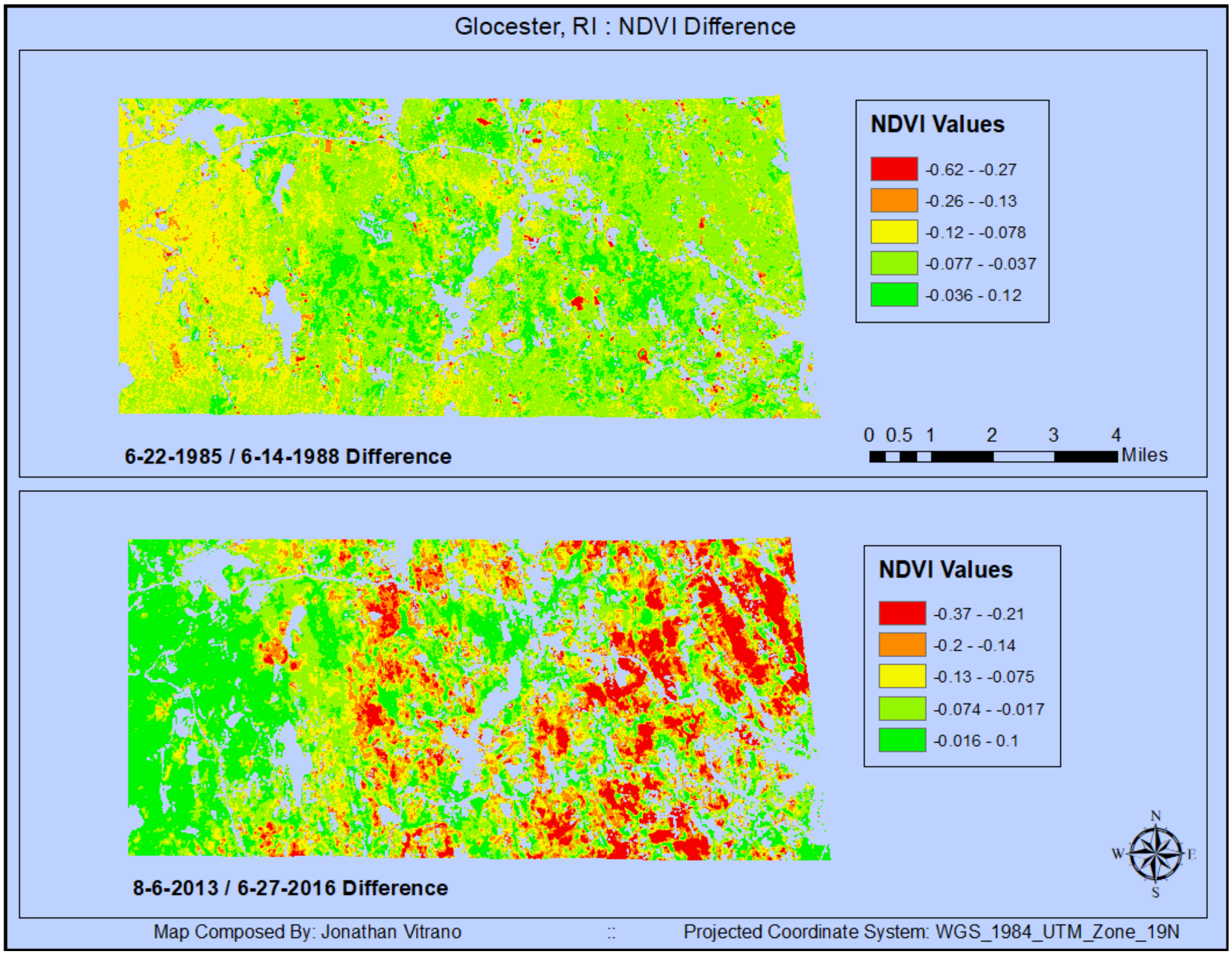

Figure 3

Figure 3 shows the clipped, vegetation only NDVI difference between 1988-1985 and 2013-2016. The values shown indicate a high negative difference in red (heavy defoliation), moderate negative difference in yellow (light defoliation), and little to no difference in green (no defoliation). These images clearly show where defoliation damage has occurred even in the 1985-1988 difference which was not as apparent in the previous NDVI images.

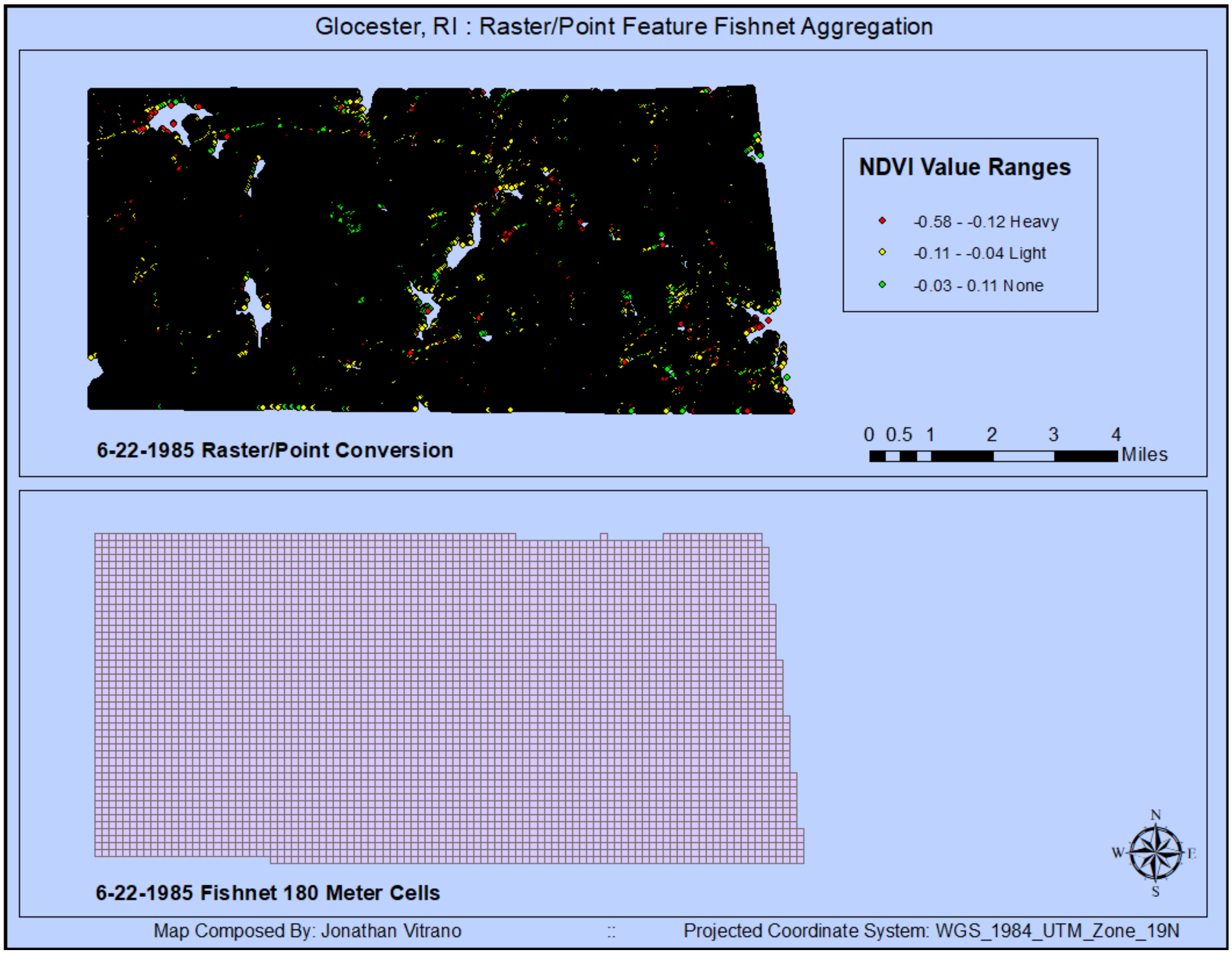

Figure 4

Figure 4 shows a conversion of the 1985 NDVI difference to a point feature (top) and the subsequent spatial joint to a 180m fishnet grid (bottom) in order to aggregate the three defoliation point class types into polygons for further cluster analysis in figures 5-10. This raster/point conversion was also performed on the 2016 NDVI difference raster as well.

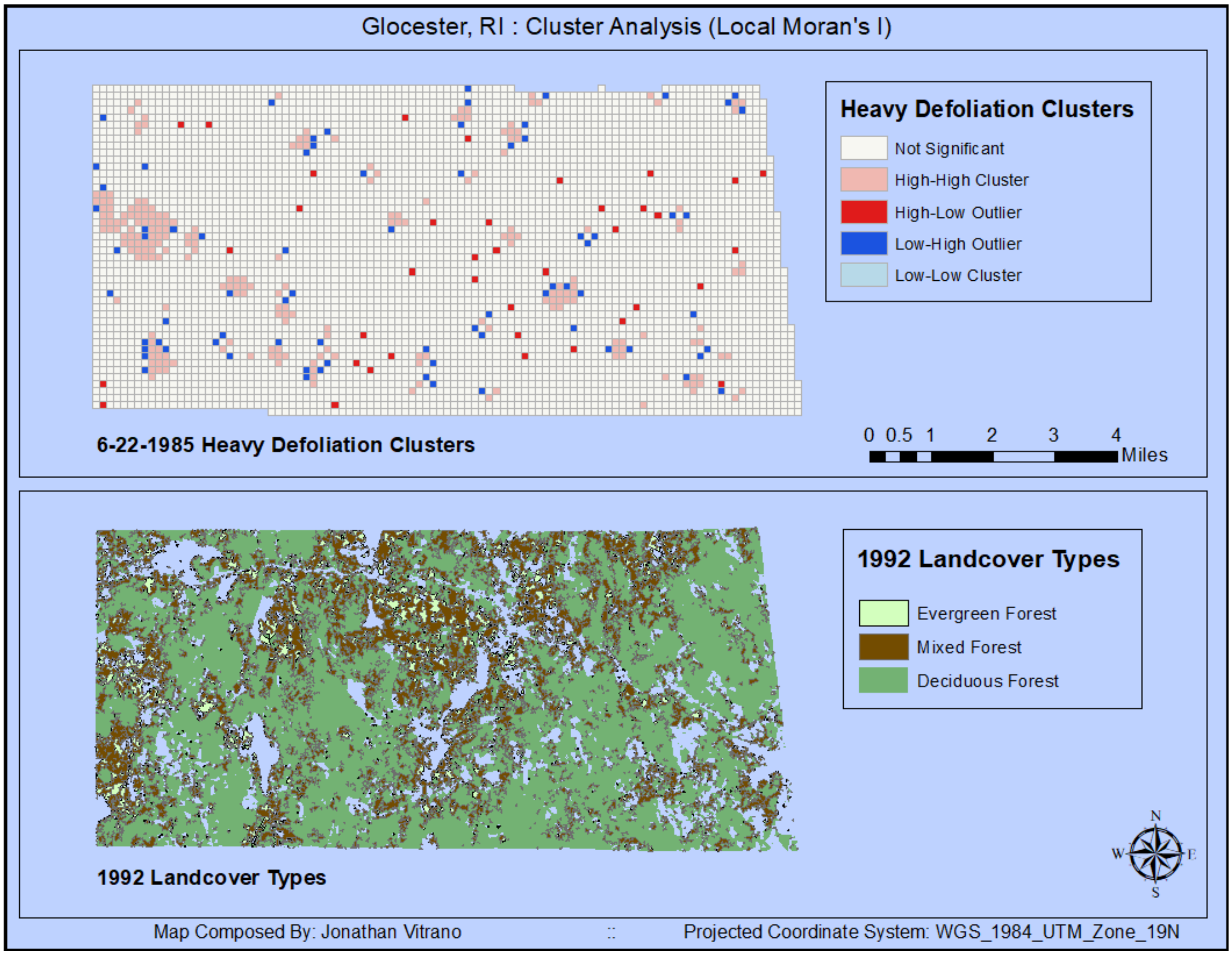

Figure 5

Figure 5 shows a Local Moran I's cluster analysis of the aggregated heavy defoliation points for the 1985 defoliation event (top). It appears that there are few clusters of heavy defoliation in 1985 and based upon the forest land cover types (bottom) it appears that the clusters occurred in mostly deciduous forests.

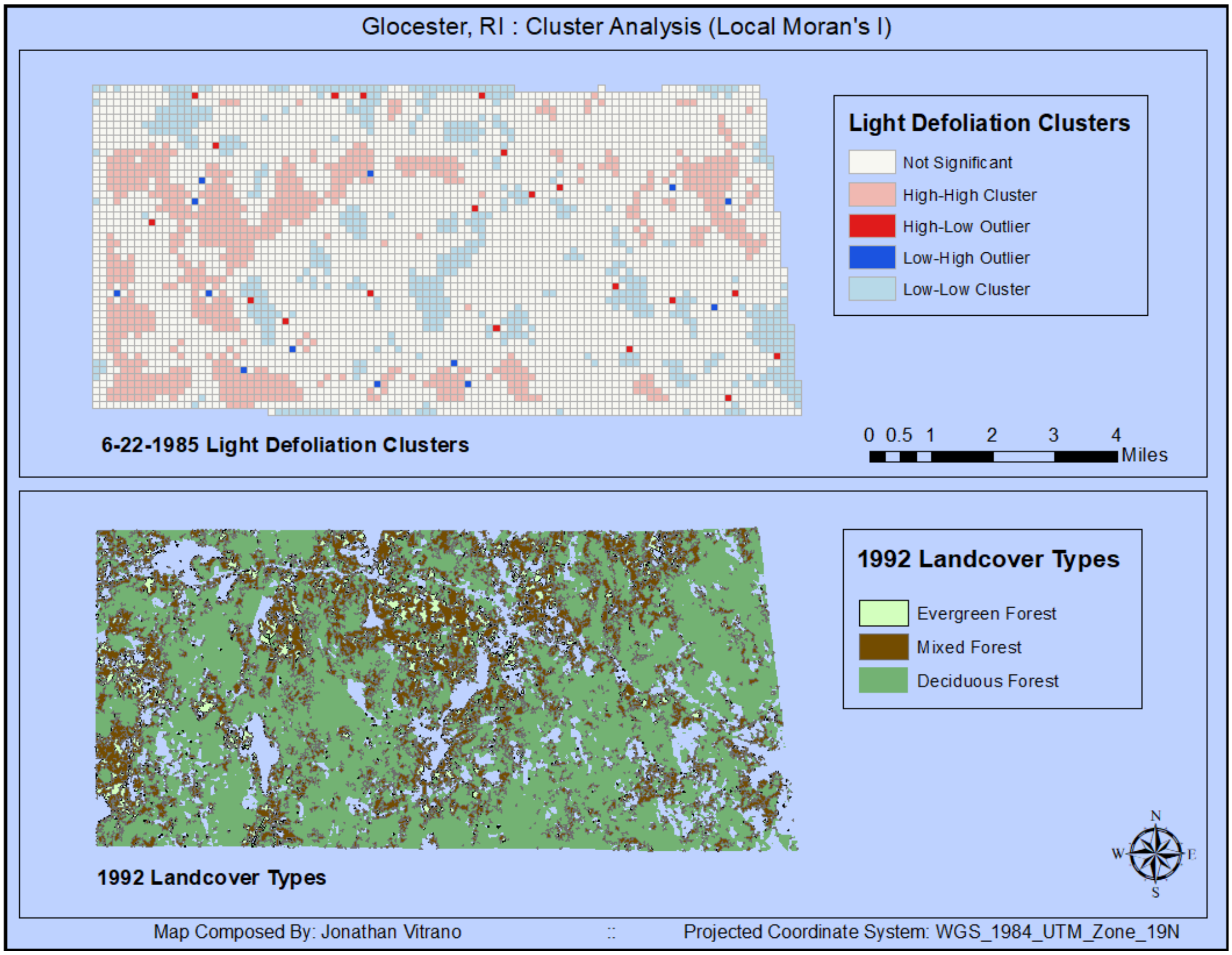

Figure 6

Figure 6 shows a Local Moran I's cluster analysis of the aggregated light defoliation points for the 1985 defoliation event (top). It appears that there are many more clusters of light defoliation in 1985 and based upon the forest land cover types (bottom) it appears that the clusters occurred in mostly deciduous forests with some occurring in mixed forests.

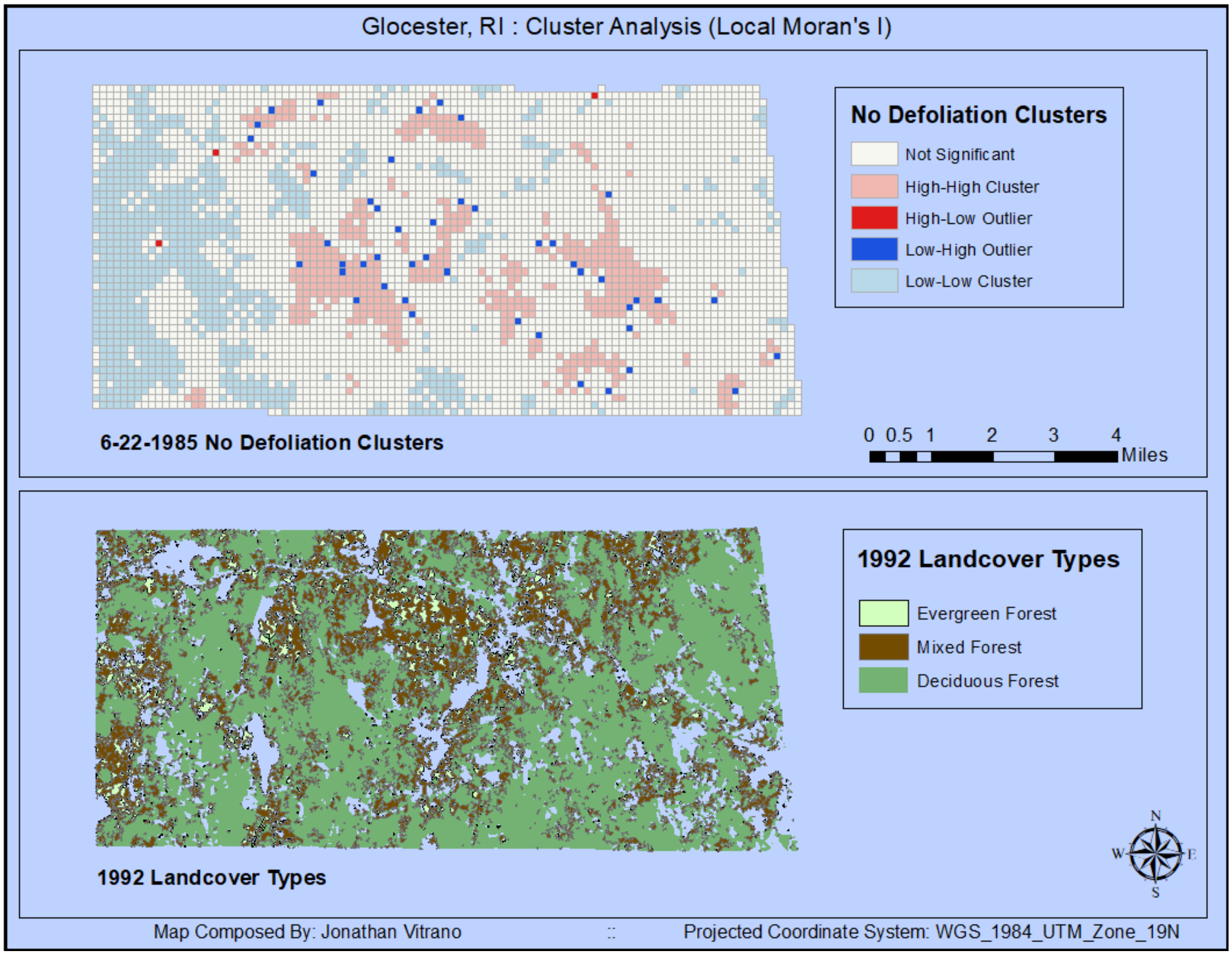

Figure 7

Figure 7 shows a Local Moran I's cluster analysis of the aggregated no defoliation points for the 1985 defoliation event (top). It appears that there are some large clusters of no defoliation in both deciduous and mixed forest areas.

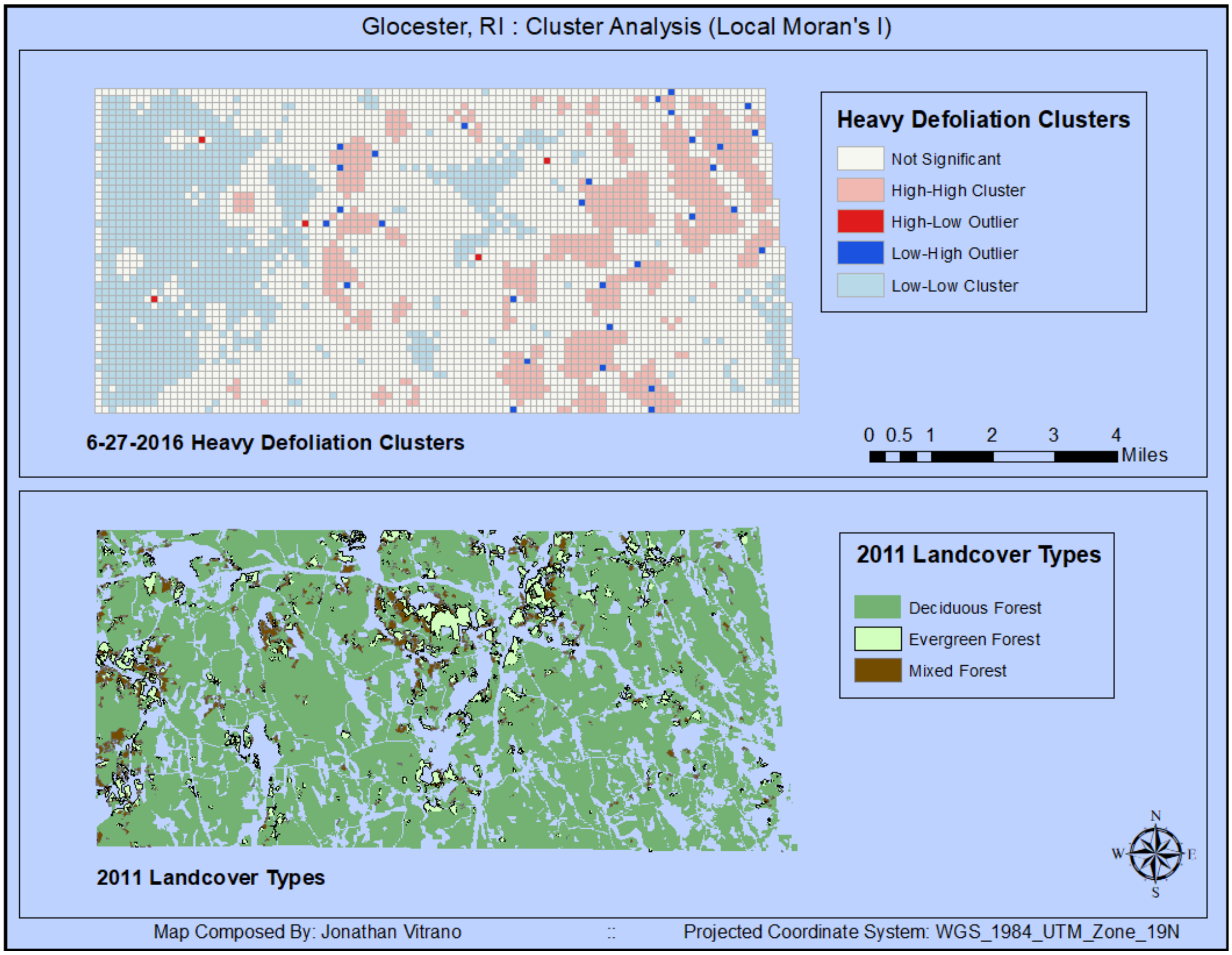

Figure 8

Figure 8 shows a Local Moran I's cluster analysis of the aggregated heavy defoliation points for the 2016 defoliation event (top). It appears that there are large clusters of heavy defoliation in the eastern and central part of Glocester and based upon the forest land cover types (bottom) it appears that the clusters occurred in mostly deciduous forests.

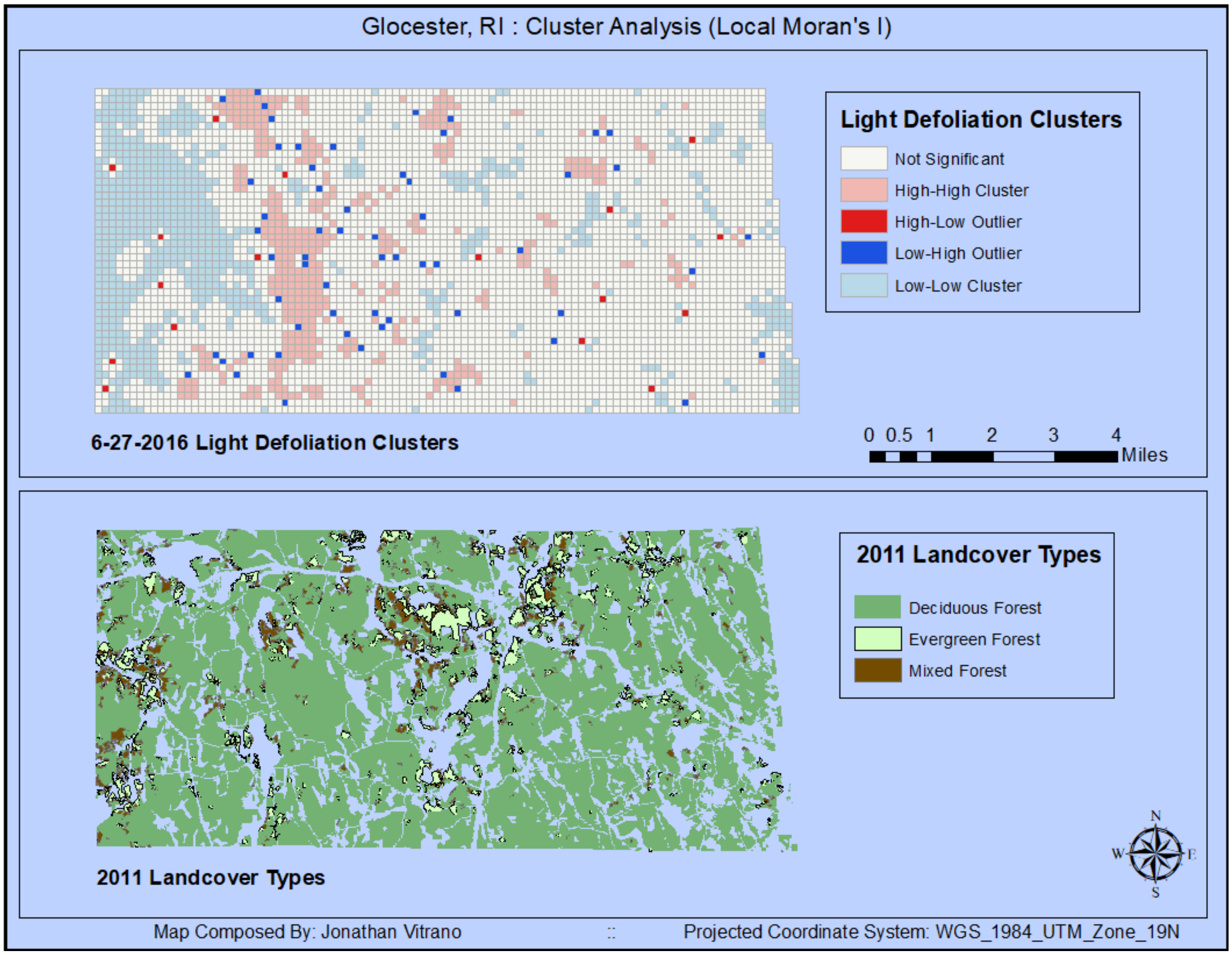

Figure 9

Figure 9 shows a Local Moran I's cluster analysis of the aggregated light defoliation points for the 2016 defoliation event (top). It appears that there are large clusters of light defoliation in the central-western portion of Glocester with some smaller, sparse clusters in the eastern area and based upon the forest land cover types (bottom) it appears that the clusters occurred in mostly deciduous forests.

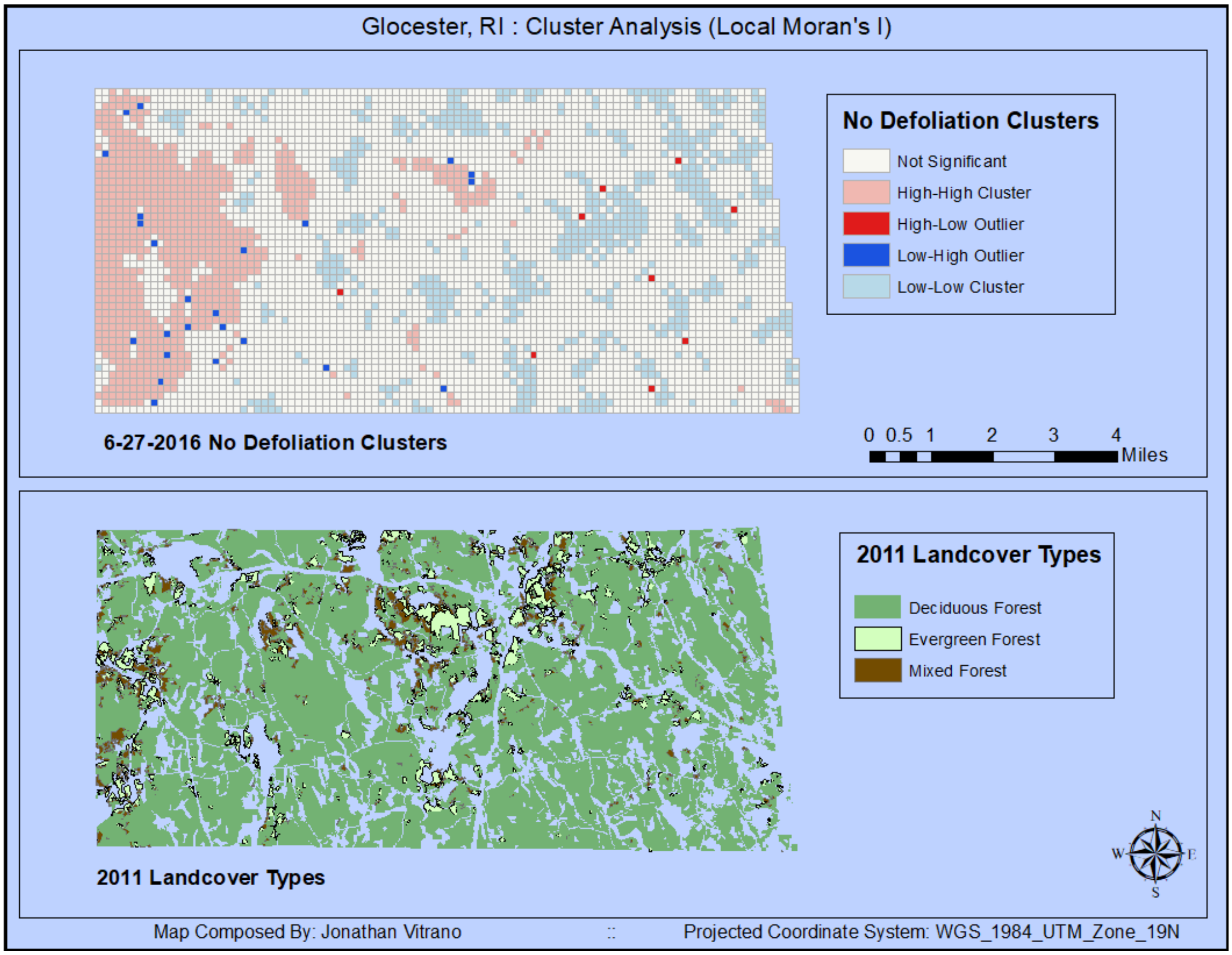

Figure 10

Figure 10 shows a Local Moran I's cluster analysis of the aggregated no defoliation points for the 2016 defoliation event (top). It appears that there are large clusters of no defoliation in the western area and a small cluster in the north-central part of Glocester. It appears that these clusters occur more frequently in mixed and evergreen forests based upon the forest land cover types (bottom); however a large part of the clusters still occurred in deciduous forests.

Discussion/Conclusion

By using Landsat satellite imagery the defoliation events of 1985 and 2016 were able to be mapped using NDVI differencing of control, non-defoliated vs defoliated dates within the June/July window of estimated defoliation events. In 2016, the NDVI difference in figure 3 clearly shows where defoliation occurred with heavy defoliation in much of eastern and central Glocester. Lighter defoliation occurred throughout the surrounding adjacent areas while much of the western section saw little to no defoliation. In 1985, the NDVI difference in figure 3 indicated a much different scenario. While defoliation was widespread, as reported at the time, it appears to be much less severe with only small pockets of heavy defoliation and a pattern of lighter concentrations of defoliation in the western part of Glocester rather than the central and eastern portion as seen in 2016.

The 1985 Local Moran's I cluster analysis backed up the defoliation information shown by the NDVI difference in figure 3. Figure 5 showed only small, sparse heavy defoliation clusters while figure 6 indicated a much higher concentration of light defoliation in the western portion of Glocester with some smaller pockets in the central and eastern areas. As expected, the non-defoliated areas clustered around the central portion of Glocester as seen in figure 7. The 2016 Local Moran's I cluster analysis also backed up the defoliation information shown by the NDVI difference in figure 3. Figure 8 showed heavy defoliation in the eastern and central portion of Glocester. Light defoliation was more heavily clustered in the central-western area with some smaller pockets scattered throughout (figure 9). Nearly all of the non-defoliated areas clustered in the western section of the town with a couple of smaller clusters near the center (figure 10).

The most surprising aspect of this study can be seen when comparing the forest land cover types to how the defoliation events tended to cluster. In 1985 (using 1992 land cover data), Glocester had a much higher percentage of mixed forest than in 2016 (using 2011 land cover data). This may have led to much lower concentration and total heavy defoliation. The lighter defoliation did appear much more widespread but it occurred mostly in deciduous forest only. Some central areas even seemed to be protected from the spread of gypsy moth caterpillars with high concentrations of non-defoliated deciduous forests (figure 7). In 2016 the forest land cover appears totally different, dominated by deciduous forests and a reduction of mixed forests from the 1992 land cover map. This may have contributed to the spread and severity of gypsy moth larvae, though other factors may be at play. It is particularly surprising that the western portion of Glocester was fairly untouched in 2016 with very low defoliation where thirty years earlier the western forests had the highest concentrations of light defoliation and defoliation in general.

This study was fairly straightforward. While it was difficult finding imagery that was cloud-free, undistorted, and lined up with the required dates, the images used did produce acceptable results. The supervised classification that was used to remove unwanted, non-vegetated areas was very useful and resulted in clearly defined NDVI difference images. The Local Moran's I cluster analysis served as a good backup to the NDVI difference in order to show where clusters of defoliation (and non-defoliation occurred). While the land cover type maps did provide some interesting insight into where defoliation tends to occur it would be interesting to pursue additional variables such as elevation, precipitation totals, tree stand age, climate data, and other factors that might further explain the spatial patterns of gypsy moth defoliation in this area as seen in a similar study by Paritsis et al. (2011). Some of this additional data might be difficult to obtain but it would be interesting to perform a geographically weighted regression to see if they correlate in any way to the defoliation events.

Overall, this study was very interesting and highlights the need for forest health monitoring and conservation efforts to protect susceptible forested areas. While the spatial analysis was able to indicate areas of clustered defoliation, there is no reason to believe that these areas will be affected the same way in the future due to the large disparity between the 1985 and 2016 events found in this study. With ever-changing climate and the subsequent land cover changes it is becoming more and more difficult to predict interactions in the environment, especially ones involving invasive species such as the gypsy moth.

References

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